Computerized Medical Imaging and Graphics 43 (2015) 78–88

Contents lists available at ScienceDirect

Computerized Medical Imaging and Graphics

journal homepage: www.elsevier.com/locate/compmedimag

Fully automated diabetic retinopathy screening using morphological component analysis

Elaheh Imani[a,1], Hamid-Reza Pourreza[a,*,1], Touka Banaee[b,1]

[a] Machine Vision Lab., Ferdowsi University of Mashhad, Mashhad, Iran
[b] Retina Research Center, Mashhad University of Medical Sciences, Mashhad, Iran

ARTICLE INFO

Article history:
Received 13 May 2014
Received in revised form 8 March 2015
Accepted 11 March 2015

Keywords:
Diabetic retinopathy screening
Retinal image quality assessment
Morphological component analysis (MCA) algorithm

ABSTRACT

Diabetic retinopathy is the major cause of blindness in the world. It has been shown that early diagnosis can play a major role in prevention of visual loss and blindness. This diagnosis can be made through regular screening and timely treatment. Besides, automation of this process can significantly reduce the work of ophthalmologists and alleviate inter and intra observer variability. This paper provides a fully automated diabetic retinopathy screening system with the ability of retinal image quality assessment. The novelty of the proposed method lies in the use of Morphological Component Analysis (MCA) algorithm to discriminate between normal and pathological retinal structures. To this end, first a pre-screening algorithm is used to assess the quality of retinal images. If the quality of the image is not satisfactory, it is examined by an ophthalmologist and must be recaptured if necessary. Otherwise, the image is processed for diabetic retinopathy detection. In this stage, normal and pathological structures of the retinal image are separated by MCA algorithm. Finally, the normal and abnormal retinal images are distinguished by statistical features of the retinal lesions. Our proposed system achieved 92.01% sensitivity and 95.45% specificity on the Messidor dataset which is a remarkable result in comparison with previous work.

1. Introduction

Diabetes mellitus (DM) has been identified as one of the leading causes of death, disability, and blindness in the world. According to World Health Organization (WHO) statistics, more than 285 million people around the world have DM and it is predicted to reach 439 million people by 2030 [1]. Diabetic retinopathy (DR) is the most common eye disease that affects patients with DM. DR is usually asymptomatic at its early stage which may only be recognized when changes in the retina have progressed to the level that makes the treatment impossible. Accurate and early detection of diabetic retinopathy is essential to reduce the blindness around the world. Therefore, maximum screening and timely re-screening uptake is highly recommended to diabetic patients. While a majority of diabetic patients do not receive regular eye examination, the diagnosis is often made after beginning of partial vision loss. There are some factors preventing patients from getting regular follow-up, including the high costs of examination and treatment combined with the shortage of ophthalmologists, especially in rural areas [2]. Normally, eye examination should be carried out every 12 months and it includes capturing and analyzing retinal images to observe the early changes of spots [3]. Recent investigations have demonstrated that diabetic retinopathy can be measured from retinal fundus images. Fig. 1 shows normal and abnormal retinal images containing various abnormal signs. Microaneurysms that appear as small red spots may lead to the hemorrhages. The so-called bright lesions like hard exudates appear as bright yellow lesions in the fundus images. As diabetic retinopathy can only be diagnosed after analyzing retinal lesions, automated image analysis, not requiring the diagnosis of an ophthalmologist, appears as an attractive option. The perceived benefits of automated diagnosis are rapid, accurate, quantified, and cost-effective processing of a large number of images.

Nevertheless, there are some problems that hinder the development of a fully automated retinal image analysis system, including the need for assessing retinal images to ensure that their quality is higher than the grading standards [4]. In a DR system, a retinal image is considered to have a poor quality if it is difficult to provide any meaningful information for passing a reliable judgment [5]. Automated analysis of retinal images with poor quality may produce unreliable results. Therefore, evaluation of the image

* Corresponding author. Tel.: +98 5138805025.
E-mail addresses: elaheh.imani@stu.um.ac.ir, elaheh.imani@gmail.com (E. Imani), hpourreza@um.ac.ir, hamid_pourreza@yahoo.com (H.-R. Pourreza), banaeet@mums.ac.ir (T. Banaee).
[1] Member of Eye Image Analysis Research Group (EIARG).

http://dx.doi.org/10.1016/j.compmedimag.2015.03.004
0895-6111/

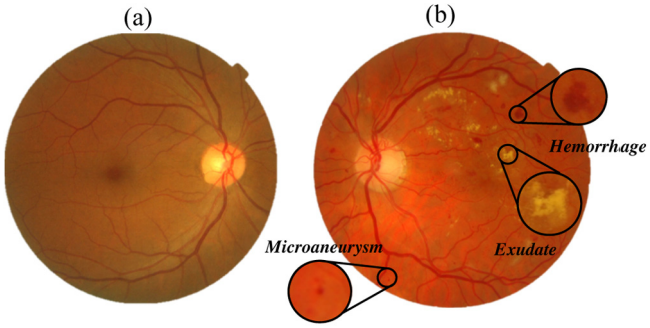

Fig. 1. Exemples of retinal images: (a) normal fundus, (b): abnormal fundus.

quality is a prerequisite for the development of automatic diabetic retinopathy screening system. The main factors that may affect the quality of retinal images are the patient's head or eye movement, poorly dilated pupils, blinking, and media opacity. Head or eye movement may lead to the generation of out-of-focus and unevenly illuminated images. Poorly dilated pupils may also affect image illumination, creating dark low-contrast images [6]. In 2006, Zimmer-Galler [7] reported that 11% of the images in their study were unreadable. It was estimated that 25% of the poor quality images were produced by the lack of patients' fixation, 25% by the lack of focus and pupil centering, and 25% by small pupil size, media opacity and instrument failure. A specific cause could not be identified for the rest of unreadable images. Some examples of poor and good quality retinal images are shown in Fig. 2.

In this paper, a fully automated diabetic retinopathy screening system with the ability of image quality assessment is developed. In the proposed system, a pre-screening algorithm is used to assess the quality of retinal images. If the quality of the image is not satisfactory, it is examined by an ophthalmologist and reacquired if necessary. Otherwise, the image is processed for DR detection. Most of the existing DR detection algorithms require the development of a specific segmentation technique for each abnormality found in the retina [8]. An algorithm that allows multiple lesions detection without requiring different segmentation algorithms is important in the development of a screening system. The main contribution of this paper is providing a novel DR detection method that is effective in dealing with the mentioned problem. This solution is based on Morphological Component Analysis (MCA) algorithm [9] which is effective in separating the contents of images. The proposed DR detection algorithm is capable of identifying different DR-related lesions such as microaneurysms, hemorrhages, and exudates using only one algorithm. This algorithm does not rely on any specific size or color of lesions, as required by some of the current lesion detectors in the literature. Extensive experiments have been conducted to demonstrate the effectiveness of this new algorithm with the experimental results on the Messidor [10] dataset showing that the proposed method is comparable to the state-of-the-art DR detection approaches.

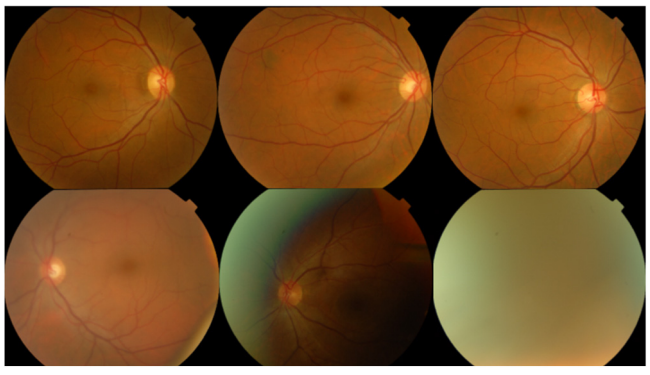

Fig. 2. Examples of good quality and poor quality retinal images: top row are good quality images and bottom row are poor quality ones.

The remainder of this paper is organized as follows. Section 2 summarizes the state-of-the-art automatic retinal image quality assessment and diabetic retinopathy detection algorithms. In Section 3, multi-scale geometric analysis algorithm is briefly described and then the Shearlet and Contourlet transforms are elaborated. The proposed system is presented in Section 4. Extensive experimental validation is reported in Section 5. Finally, concluding remarks and suggestions for future studies are given in Sections 6 and 7, respectively.

2. Related works

The first part of this section is devoted to the review of literature on the retinal image quality assessment algorithms. The second part also reviews the diabetic retinopathy detection methodologies.

2.1. Quality assessment

Several approaches have been developed to automatically determine the quality of retinal images. These approaches can be classified into two categories. The first category is based on generic image quality parameters such as sharpness and contrast. In 2001, Lalondey [11] proposed a method based on the histogram of edge magnitude and the local histogram of pixel gray-scale values to evaluate image focus and illumination. In this method, the quality of a given image is determined through the difference of its histogram and the mean histogram of a set of high quality images as a reference. In 2009, Davis et al. [12] focused their quality assessment on contrast and luminance features. In the same year, Bartling [13] demonstrated the application of sharpness and illumination parameters. The illumination was measured by an evaluation of contrast and brightness and the degree of sharpness was calculated from the spatial frequencies of the image. Moreover, Paulus et al. [14] employed a combination of image structure clustering, Heralick features and sharpness measures based on image gradient magnitudes for classifying poor quality retinal images. In 2012, Dias et al. [4] developed a quality assessment method based on a fusion of generic image quality indicators such as image color, focus, contrast, and illumination.

The second category of the approaches being made so far relies on the structural information of retinal images. This information requires segmentation of anatomical landmarks in the image. A combination of the field definition and image clarity was employed by Fleming el al. [15]. The clarity analysis was carried out by the vasculature of a circular area around the macula. In 2006, Niemeijer [16] introduced an algorithm based on the clustering of filter bank response vectors in order to obtain a compact representation of the image structures. The compact representation and image histograms were used to design a statistical classifier capable of distinguishing retinal images with a high or low quality. In 2008, Giancardo et al. [17] assessed the quality of retinal images based on the eye vasculature. Vessels' density in the local patches were used as feature vectors for quality assessment. In 2011, Hunter et al. [6] proposed a method based on the clarity of retinal vessels within the macula region as well as the contrast between fovea area and background of the retina.

The main goal of the approaches in the first category is to use simple image measurements to estimate the image quality. These measurements avoid eye structure segmentation procedures which reduces the computational complexity [4]. On the other hand, approaches in the second category require anatomical landmarks segmentation which is both complex and error